First observation and measurement of the resonant structure of the $\Lambda_b^0 \to \Lambda_c^+ \pi^- \pi^+ \pi^-$ decay mode

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We present the first observation of the $\Lambda_b^0 \to \Lambda_c^+ \pi^- \pi^+ \pi^-$ decay using data from an integrated luminosity of approximately 2.4 fb^{-1} of $p\overline{p}$ collisions at $\sqrt{s}$=1.96 TeV, collected with the CDF II detector at the Fermilab Tevatron. We also present the first observation of the resonant decays $\Lambda_b^0 \to \Sigma_c(2455)^0 \pi^+ \pi^- \to \Lambda_c^+ \pi^- \pi^+ \pi^-$, $\Lambda_b^0 \to \Sigma_c(2455)^{++} \pi^- \pi^- \to \Lambda_c^+ \pi^- \pi^+ \pi^-$, $\Lambda_b^0 \to \Lambda_c(2595)^+ \pi^- \to \Lambda_c^+ \pi^- \pi^+ \pi^-$ and $\Lambda_b^0 \to \Lambda_c(2625)^+ \pi^- \to \Lambda_c^+ \pi^- \pi^+ \pi^-$, and measure their relative branching ratios.

1 Introduction

Presented here is the observation of the $\Lambda_b^0 \to \Lambda_c^+ \pi^- \pi^+ \pi^-$ decay and resonant structure in analogy to the decay structure observed in the $\Lambda_b^0 \to \Lambda_c^+ \pi^+ \pi^- \mu^- \overline{\nu}_\mu$ channel [1]. All new measurements of the Λ_b^0 branching ratios can be compared to theoretical predictions in the heavy quark effective theory (HQEF) approximation [2].

This measurement is based on data from an integrated luminosity of approximately 2.4 fb^{-1} of $p\overline{p}$ collisions at $\sqrt{s}$=1.96 TeV, collected with the CDF II detector [3], using two-track impact parameter triggers. Unless stated otherwise, branching fractions, fragmentation functions, and lifetimes used in the analysis are obtained from the Particle Data Group world averages [4].

2 Event selection and signal yields

The event reconstruction and selection has been optimized in order to maximize the statistical significance of the total number of Λ_b^0 decays observed on the data. The Λ_c^+ candidates are reconstructed in the $\Lambda_c^+ \to pK^- \pi^+$ channel requiring a vertex χ^2 probability in excess of 10^{-4}, a transverse decay length in excess of 200 μm, $p_T(p) > p_T(\pi^+)$, $p_T(\Lambda_c^+) > 4$ GeV/c and the Λ_c^+ invariant mass in the 2.24-2.33 GeV/c^2 mass range.

The Λ_b^0 candidates are reconstructed by further adding to the Λ_c^+ candidates three pion candidate tracks, with $\eta\phi$-opening $\Delta R(3\pi)$ smaller than 1.2. The Λ_b^0 candidate is required to have a vertex χ^2 probability in excess of 10^{-4}, a transverse decay length in excess of 200 μm and a significance in excess of 16, an impact parameter smaller than 70 μm, and a transverse momentum in excess of 9 GeV/c.

The resulting distribution of the invariant mass difference $m(\Lambda_c^+\pi^-\pi^+\pi^-) - m(\Lambda_c^+)$ with the $\Lambda_b^0 \to \Lambda_c^+\pi^-\pi^+\pi^-$ signal peak, is shown in Figure 1. A total signal yield of 848±93 candidates is evaluated with an unbinned likelihood fit using a Gaussian distribution for the signal, an exponential distribution for the background, and Monte Carlo templates for B^0 and B_s^0 backgrounds. In the following Λ_b^0 candidates have been selected within 48 MeV/c^2 of the mass peak.

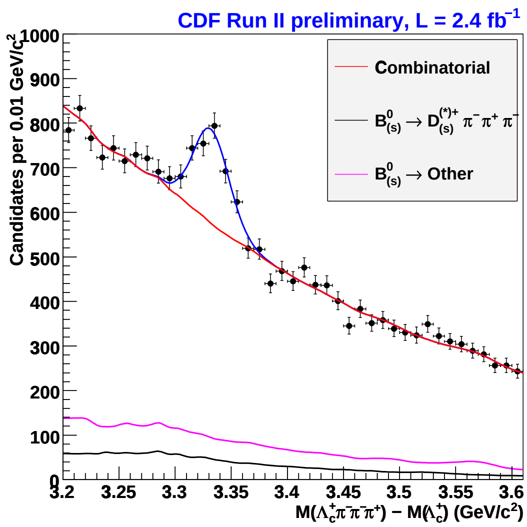

Figure 1: The reconstructed invariant mass difference $m(\Lambda_c^+\pi^-\pi^+\pi^-) - m(\Lambda_c^+)$, after applying optimized cuts, showing the total $\Lambda_b^0 \to \Lambda_c^+\pi^-\pi^+\pi^-$ signal yield.

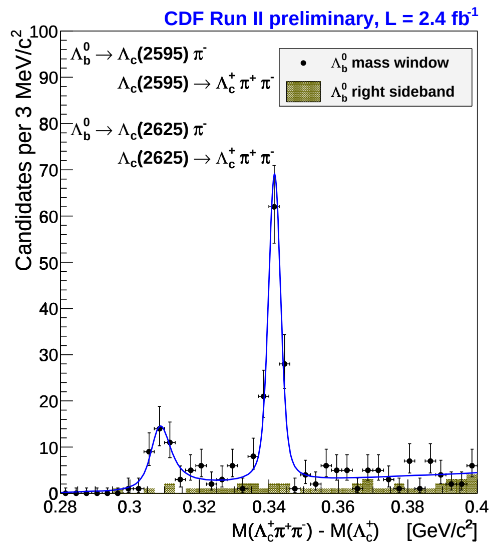

Figure 2: The reconstructed invariant mass difference $m(\Lambda_c^+\pi^-\pi^+) - m(\Lambda_c^+)$ within the Λ_b^0 mass window, showing the $\Lambda_b^0 \to \Lambda_c(2595)^+\pi^- \to \Lambda_c^+\pi^-\pi^+\pi^-$ and $\Lambda_b^0 \to \Lambda_c(2625)^+\pi^- \to \Lambda_c^+\pi^-\pi^+\pi^-$ signal yields.

The mass difference $\Delta m^{-+} = m(\Lambda_c^+\pi^-\pi^+) - m(\Lambda_c^+)$ for selected Λ_b^0 candidates is shown in Figure 2, with the two peaks from $\Lambda_c(2595)^+$ and $\Lambda_c(2625)^+$ decays. A fit performed with two signal peaks and a linear background yields 46.6±9.7 $\Lambda_b^0 \to \Lambda_c(2595)^+\pi^-$ candidates and 114±13 $\Lambda_b^0 \to \Lambda_c(2625)^+\pi^-$ candidates.

Finally the mass differences $m(\Lambda_c^+\pi^+) - m(\Lambda_c^+)$ and $m(\Lambda_c^+\pi^+) - m(\Lambda_c^+)$ are shown in Figure 2, for selected Λ_b^0 candidates, after removing $\Lambda_c(2595)^+$ and $\Lambda_c(2625)^+$ decays with the $\Delta m^{-+} > 360$ MeV/c^2 requirement. Separate fits of the two signal contributions yield 41.5±9.3 $\Lambda_b^0 \to \Sigma_c(2455)^0\pi^+\pi^-$ candidates and 81±15 $\Lambda_b^0 \to \Sigma_c(2455)^{++}\pi^+\pi^+$ candidates.

3 Results

Results are expressed in terms of relative branching fractions between the above resonant decay modes, correcting for the relative channel efficiencies with Monte Carlo simulations. Several sources of systematic effects have been considered, and the dominant uncertainties come from the Λ_b^0 and Λ_c^+ polarization uncertainty, and on the unknown fraction of non-resonant decays.

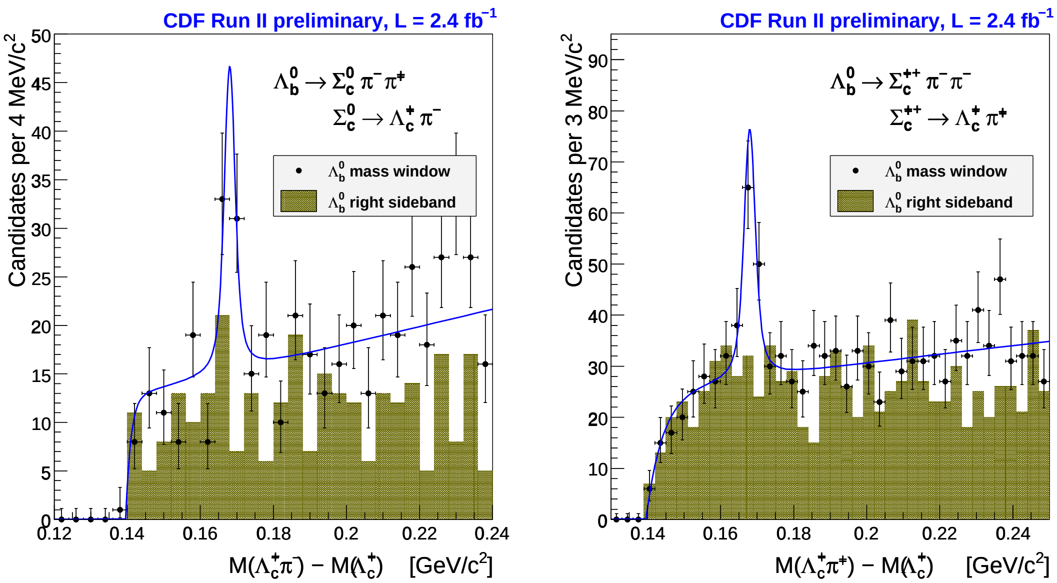

Figure 3: The invariant mass difference $m(\Lambda_c^+\pi^-) - m(\Lambda_c^+)$ (left) and $m(\Lambda_c^+\pi^+) - m(\Lambda_c^+)$ (right) for selected Λ_b^0 candidates, after removing events with $\Lambda_c(2595)^+$ and $\Lambda_c(2625)^+$ decays, and showing respectively the presence of $\Lambda_b^0 \to \Sigma_c(2455)^0 \pi^+\pi^-$ and $\Lambda_b^0 \to \Sigma_c(2455)^{++}\pi^-\pi^-$ signals.

In summary the measured relative branching fractions are the following

$$\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c(2595)^+\pi^- \to \Lambda_c^+\pi^-\pi^+\pi^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\pi^-\pi^+\pi^-)} = (2.5 \pm 0.6(\mathrm{stat}) \pm 0.5(\mathrm{syst})) \times 10^{-2}$$
$$\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c(2625)^+\pi^- \to \Lambda_c^+\pi^-\pi^+\pi^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\pi^-\pi^+\pi^-)} = (6.2 \pm 1.0(\mathrm{stat})^{+1.0}_{-0.9}(\mathrm{syst})) \times 10^{-2}$$
$$\frac{\mathcal{B}(\Lambda_b^0 \to \Sigma_c(2455)^{++}\pi^-\pi^- \to \Lambda_c^+\pi^-\pi^+\pi^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\pi^-\pi^+\pi^-)} = (5.2 \pm 1.1(\mathrm{stat}) \pm 0.8(\mathrm{syst})) \times 10^{-2}$$
$$\frac{\mathcal{B}(\Lambda_b^0 \to \Sigma_c(2455)^0\pi^+\pi^- \to \Lambda_c^+\pi^-\pi^+\pi^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\pi^-\pi^+\pi^-)} = (8.9 \pm 2.1(\mathrm{stat})^{+1.2}_{-1.0}(\mathrm{syst})) \times 10^{-2}$$
$$\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c(2595)^+\pi^- \to \Lambda_c^+\pi^-\pi^+\pi^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c(2625)^+\pi^- \to \Lambda_c^+\pi^-\pi^+\pi^-)} = (40.3 \pm 9.8(\mathrm{stat})^{+2.3}_{-1.8}(\mathrm{syst})) \cdot 10^{-2}$$
$$\frac{\mathcal{B}(\Lambda_b^0 \to \Sigma_c(2455)^{++}\pi^-\pi^- \to \Lambda_c^+\pi^-\pi^+\pi^-)}{\mathcal{B}(\Lambda_b^0 \to \Sigma_c(2455)^0\pi^+\pi^- \to \Lambda_c^+\pi^-\pi^+\pi^-)} = (58.1 \pm 16.9(\mathrm{stat})^{+6.3}_{-9.1}(\mathrm{syst})) \cdot 10^{-2}$$
$$\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c(2625)^+\pi^- \to \Lambda_c^+\pi^-\pi^+\pi^-)}{\mathcal{B}(\Lambda_b^0 \to \Sigma_c(2455)^{++}\pi^-\pi^- \to \Lambda_c^+\pi^-\pi^+\pi^-)} = 1.20 \pm 0.26(\mathrm{stat})^{+0.05}_{-0.09}(\mathrm{syst})$$

where the first error is statistical and the second is from systematic uncertainties.

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